# A NEW RELEASE OF MODIFIED DISSIMILARITY MAXIMIZATION METHOD FOR REAL TIME ALTERNATIVE ROUTING SELECTION IN AN FMS

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# A NEW RELEASE OF MODIFIED DISSIMILARITY MAXIMIZATION METHOD FOR REAL TIME ALTERNATIVE ROUTING SELECTION IN AN FMS

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**ABSTRACT:** *Routing flexibility is one of among common types of flexibilities that exist in flexible manufacturing systems. It can be found in each system that contains alternative, identical machines or redundant machine tools.*
*Modified DMM (Dissimilarity Maximization Method) is one of the most recent proposed heuristics for real time FMS scheduling by considering the routing flexibility. This rule is developed for part routing decisions by using a dissimilarity coefficient used to differ the routings from others in terms of the machines types, in order to reduce the congestion in the system and consequently improving the system throughput.*
*This work presents an improvement of this method with a new dissimilarity coefficient which takes into account the breakdowns probability in the procedure of selecting a routing for a part.*
*The simulation experimentation results obtained with presence of breakdowns after several simulations in a typical flexible manufacturing show that for an overloaded system, the new approach improve clearly the system performances in terms the production rate, machines and material handling utilisation rate.*

**KEYWORDS:** *Flexible manufacturing systems, Alternative routing, Routing selection rule, Routing flexibility.*

## 1 INTRODUCTION

A Flexible Manufacturing System (FMS) is an integrated system composed of automated workstations such as computer numerically controlled (CNC) machines with tool changing capability, a material handling and storage system such as automated guided vehicles or conveyors, and a computer control system which controls the operations of the whole system (MacCarthy and Liu, 1993). It is designed to combine high productivity and production flexibility. But to achieve simultaneously these two goals, a FMS needs an adapted control. One of the most important and difficult problem to solve in order to control a FMS is to propose an efficient schedule for the production planning.

The scheduling problem can be considered as the allocation of a set of tasks to a set of resources under specified constraints (French, 1982; Pinedo, 2008). A job is defined as a set of interrelated tasks.

Over the last three decades, many researchers have extensively investigated the scheduling problems for FMS's. As a result, various types of scheduling problems are solved in different FMS environments, a number of approaches, procedures and varieties of algorithms are employed to obtain optimal or near optimal schedules in these systems. Traditionally, different analytical tools such as mathematical modelling, dynamic programming, branch and bound methods can be employed to obtain the optimal schedule. But according to (Akyol and Araz, 2007) these approaches have been addressed in a static scheduling environment where the system attributes are deterministic. However, most manufacturing systems operate in dynamic environments. For this reason, the schedule developed beforehand may become inefficient in a dynamic environment characterised by uncertain changes of events including in particular machine failures, arrival of urgent jobs…

In these environments, scheduling decisions are to be made in a very short time as the time required to generate a schedule becomes relatively more important factor than merely finding a best quality schedule in an extended period of time. Moreover, schedule is required to be highly reactive to cope with unanticipated circumstances (Shahzad, 2011).

The scheduling problems in dynamic environments are best tackled by a synergy of scheduling algorithms and heuristics. But according to Saygin *et al.* (2001) many of them do not consider the influence of routing flexibility and most of the studies that consider routing flexibility in FMS focus on the problem of routing selection prior to production. To cope with this drawback, they proposed a concept named the dissimilarity maximisation method (DMM) (Saygin and Kilic, 2004), for process plan selection in order to minimise the congestion in the system and, hence, improve the system throughput. The concept of this method is based on the objective of maximising the dissimilarities among the busy alternative routings. DMM uses a dissimilarity coefficient which is based on the types of machines in routings. It selects a routing for each part so that the cumulative dissimilarity, in terms of machine tool requirements, is maximised.

In the DMM rule proposed by Saygin and Kilic (2004), once a routing is selected by a part, this routing cannot be used by another part as long as the first part did not leave the system. Thus each routing can contain only one part at the time. To improve the original DMM rule, Hassam and Sari (2010) proposed a modified DMM rule which is an alternative routing selection routing rule based on the same principle but which enables assigning several parts to only one routing and consequently improve the system performances. But these approaches consider the system under study without any perturbation, especially they do not take into account machine breakdowns.

In this paper, a new release of the modified DMM rule is proposed in order to improve the performances of the production system. This proposition aims to keeping the same principle of the modified DMM rule but by considering the machines breakdowns in the integer program formulation used. In this approach the dissimilarity coefficient is based on the means time between failures (MTBF) of the machines contained in the different routings. Our approach is tested in a typical flexible manufacturing system that consists of seven machining centres, a loading and an unloading area, and six different part types. Owing to the existence of identical machining centres, the part types have alternative routings (their number varies between 2 and 8). The modified DMM method is used as a comparison basis to evaluate the performances of the proposed method.

The simulation results show that the proposed approach outperforms the modified DMM on the basis of the production rate, machines and material handling utilization rate for an overloaded system, but it has a negative impact on the work in process.

The remainder of this paper is organized as follows. The related literature is given in the next section. Then, section 3 describes the simulation model developed in this study. In section 4, we define modified DMM and the new release of modified DMM methods. Simulation results are given in section 5. Finally, the conclusions and recommendations for future work are presented.

## 2 LITERATURE REVIEW

To justify their relatively high investment, it is of utmost importance to make full use of the flexibilities that the FMS offers. One type of flexibility FMSs offer is routing flexibility. The routing flexibility has been defined in various ways. Ghosh and Gaimon (1992) stated that the routing flexibility is the capability of processing a part type using alternate routings through machines. Joseph and Sridharan (2011a) defined it as the ability of a system to provide multiple alternate routes to produce a set of parts economically and efficiently. According to Saygin and Kilic (2004) if machines are tooled properly, alternative routings can provide many benefits, such as improved production rate, improved utilization rates, and reduced work-in-process inventory. Therefore, there are several researches that investigate this type of flexibility. Many papers defined methods for measuring the routing flexibility. Joseph and Sridharan (2011b) developed a discrete event simulation model of an FMS with a dynamic arrival of part types for evaluating the routing flexibility in terms of different measures such as routing efficiency, routing versatility, routing variety and routing flexibility. Yu and Greene (2009) developed an effective quantitative measurement technique that can be utilized for evaluating routing flexibility for a flexible multi stage production system. Wahab and Stoyan (2008) proposed mathematical models to measure machine and routing flexibilities by integrating a variety of technological attributes and elements within manufacturing systems like the availability or utilisation of alternative routes. Chang (2007) developed an approach for routing flexibility measurement that incorporates three attributes: routing efficiency, routing versatility and routing variety including several dimensions such as time dimension, cost dimension...

In the existing literature on dynamic part routing, there are many strategies of operational decisions of an FMS based on AI techniques such as fuzzy logic and metaheuristics… Caprihan *et al.*, 2006 proposed a novel fuzzy logic-based dispatching strategy to cope with a specific manifestation of information delays, called status review delay within FMSs. The developed fuzzy dispatching strategy (FDS) provides an appropriate alternative to conventional dispatching strategies such as work-in-next-queue (WINQ) and number-in-next-queue (NINQ). Buyurgan and Saygin (2008) presented a framework that employs the analytical hierarchy process (AHP) in advanced manufacturing systems for real-time scheduling and part routing. This framework includes an extended finite state machine and a scheduler model to facilitate dynamic, short-term decision making, which uses AHP to assess possible future states in a limited look-ahead horizon by comparing the performance measures of each state and introducing pair wise comparison of dynamic performance measures in future system states to the real-time scheduling and part routing decisions.

This work extends the research conducted in (Buyurgan and Mendoza, 2006) and (Buyurgan and Saygin, 2006). The former utilize a pre-emptive goal programming method to evaluate possible future states of a manufacturing system. These states are ranked based on the predetermined priority of performance measures, and the state with the highest ranking is selected as the preferred future behaviour. In the latter, where uncertainty and vagueness are introduced to the future-state assessment process, performance measures are represented in fuzzy sets to incorporate the uncertain and complex correlation among different criteria into the decision making process, a combined objective function called desirability is determined for each possible future system state, and the most desirable state (that is, the state with the highest desirability value) is chosen.

To address the above routing flexibility problems some researchers used metaheuristics. Zhao and Wu, 2001 suggested a genetic algorithm (GA) to solve the job-sequencing problem for a production shop that is characterized by flexible routing and flexible machines. Rossi and Dini (2007) proposed an ant colony optimisation-based software system for solving FMS scheduling in a job-shop environment with routing flexibility, sequence-dependent setup and transportation time. In (Souier *et al.*, 2010a) several meta heuristics (the simulated annealing (SA), genetic algorithm (GA), taboo search (TS), ant colony optimization (ACO) and particle swarm optimization (PSO), Electromagnetism Like Method (EM)) are adapted for solving the alternative routing selection problem in a flexible manufacturing system with a dynamic arrival of parts. In (Souier *et al.*, 2010b) it is found that the real time rescheduling of the loading station improve the system performances when the same metaheuristics have been adapted to solve the same problem.

Some interesting studies offering different heuristic rules exist in the literature. ElMekkawy and ElMaraghy (2003) developed a rescheduling algorithm that uses time petri-nets and the minimal siphons concept, to deal with sources of disturbance such as machine breakdowns in real-time. Sabuncuoglu and Lahmar (2003) studied the machine loading problem. In their work, they compared operation aggregation and disaggregation policies in a random flexible manufacturing system (FMS) and analyzed its interaction with other factors such as routing flexibility, sequencing flexibility, machine load, buffer capacity, and alternative processing-time ratio. Ozmutlu and Harmonosky (2005) presented an efficient continuous real-time routing strategy, namely threshold-based alternate routing (TAR), to minimize mean flowtime of parts in a FMS with routing flexibility. Piplani and Wetjens (2007) prsented two rules for parts dispatching, namely 'least reduction in entropy' and 'least relative reduction in entropy' based on entropic measures of part routing flexibilities

Saygin and Kilic, (1999) present a framework to integrate flexible process plans with off-line scheduling in FMS. They propose a concept, namely the dissimilarity maximisation method (DMM), for process plan selection in order to minimise the congestion in the system and, hence, improve the system throughput. Saygin *et al.*, (2001) tested the effectiveness of the dissimilarity maximisation method for real-time FMS scheduling when FIFO is used for selection. In their model DMM is selected because it captures the system-level information, thus it is not myopic in nature and it makes use of operation and routeing flexibility. Simulation results show that DMM/FIFO outperforms FIFO/FA (First Available) and EPL (*Equal Probability Loading*) on the basis of system throughput. In (Saygin and Kilic, 2004) authors combined these three priority rules for routing (i.e., machine) selection with seven priority rules for selecting parts awaiting service at machine buffers. The simulation results show that DMM outperforms the other two routing selection rules on production rate regardless of the part selection rule used, and its performance is highly dependent on the part selection rules it is combined.

When Hassam and Sari (2010) studied the DMM method they notice some weakness when the system is overloaded. Therefore, in order to overcome this weakness and improve the performances of the production system, they proposed a rule called modified DMM which is an improvement of the DMM rule. This approach has been studied with simulation in comparison with DMM. The results show that the Modified DMM outperforms DMM on system throughput in a saturation case, increases the utilization rate of machines and material handling system.

In this work, which is an improvement of this rule, the machines states are taken into account in routings decisions procedure in order to be more responsive to the changes in the system status.

## 3 DESCRIPTION OF THE FLEXIBLE MANUFACTURING SYSTEM

The FMS environment used in our work is drawn from the literature (Saygin and Kilic, 1999, 2004), it contains seven machines, a loading station, an unloading station, and one automated guided vehicle (AGV). Six different types of parts are considered for production in the system.

Each machine has an input buffer (I) and an output buffer (O). The loading station also contains an input buffer. The configuration of the FMS is given in figure 1. The studied operations on the flexible production system are based on the following assumptions:

- *The alternative routings of each part type are known before the start of production.*
- *The processing time is known and it includes tool change, set-up, and machining times.*

- *The processing time of an operation is the same on the alternatives machines identified for this operation.*
- *Each machine can process one part at a time.*
- *The material handling system is available at all times.*

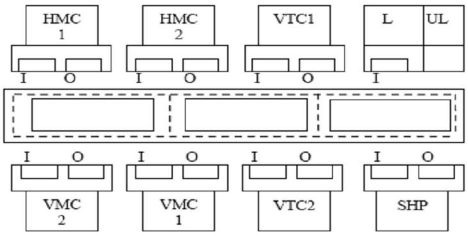


Figure 1: Configuration of the FMS model

HMC: Horizontal Machining centre
VMC: Vertical Machining centre
VTC: Vertical Turning centre
SHP: Shaper
L: Loading Station
UL: Unloading Station
I: Input Buffer,
O: Output Buffer
- - AGV routes

The alternative routing and the processing time for each type of part and the production ratio of the part types that are randomly arriving to the loading station are given in table 1.

| Part type and production ratio | Routings (processing time) | Number of different routings |
|---|---|---|
| A (17%) | L – $VTC_{1\ or\ 2}$ (30) – $VMC_{1\ or\ 2}$ (20) – UL | 4 |
| B (17%) | L – $VTC_{1\ or\ 2}$ (20) – SHP (1) – $VMC_{1\ or\ 2}$ (15)-UL | 4 |
| C (17%) | L – $VTC_{1\ or\ 2}$ (40) – $VMC_{1\ or\ 2}$ (25) – UL | 4 |
| D (21%) | L – $VTC_{1\ or\ 2}$ (40) – SHP (1) – $VTC_{1\ or\ 2}$ (20) – $HMC_{1\ or\ 2}$ (35)– UL | 8 |
| E (20%) | L – $VTC_{1\ or\ 2}$ (25) – SHP (1) – $VTC_{1\ or\ 2}$ (35) – $HMC_{1\ or\ 2}$ (50)– UL | 8 |
| F (8%) | L –$HMC_{1\ or\ 2}$ (40) – UL | 2 |

Table 1: Alternative routings of part types

Owing to the existence of identical machining centres ($VTC_1$ and $VTC_2$, $VMC_1$ and $VMC_2$, $HMC_1$ and $HMC_2$) in the FMS, the part types have alternative routings. For example, the parts type A which their arrival rate in the order queue is 17 % and processed by two types of machines $VTC_1$ or $VTC_2$ and $VMC_1$ or $VMC_2$ with the same processing time in the identical machines can follow four routings:

L – $VTC_1$ (30) – $VMC_1$ (20) – UL
L – $VTC_1$ (30) – $VMC_2$ (20) - UL
L – $VTC_2$ (30) – $VMC_1$ (20) - UL
L – $VTC_2$ (30) – $VMC_2$ (20) – UL

# 4 SIMULATED METHODS USED FOR THE REAL TIME ALTERNATIVE ROUTINGS SELECTION

## 4.1 Modified Dissimilarity Maximization Method (DMM) for Real Time Routing Selection

The Modified DMM rule (Hassam and Sari, 2010) was developed based on the DMM rule (Saygin and Kilic, 2004). Both of DMM and modified DMM are inspired from the group technology, developed for FMS real time scheduling, in order to reduce congestion and increase the rate of production of FMS. Their concepts are based on the objective of maximising the dissimilarities among the alternative routings, in terms of machine tool requirements, using a dissimilarity coefficient; which is based on the types of machines in routings. So, the selection of a routing among alternative routings of each part is performed according to the maximization of the sum of the dissimilarity coefficients. In this scope, the following notations are used:

n: Number of parts.
q: Number of routings.
$D_{ij}$ : dissimilarity between routings i and j.
$C_{ij}$ = 1 if routing j belongs to the routings of part i. Otherwise, $C_{ij} = 0$
$X_j = 1$ if routing j is selected. Otherwise, $X_j = 0$
$S_j$: Sum of maximum dissimilarity.
$N_{ij}$: Number of machines that are not common in both routing i and j
$T_{ij}$: Total number of machine types in both routing.

The dissimilarity coefficient (dissimilarity of machine type) between two routing i and j is defined as follows (Saygin and Kilic, 1999, 2004):

$$D_{ij} = \frac{N_{ij}}{T_{ij}} \quad (1)$$

For the selection of alternative routing, an integer linear program formulation, as shown below, is developed (Saygin and Kilic, 1999, 2004):

$$S_j = Max \sum_{i=1}^{q} \sum_{j=1}^{q} X_j D_{ij} \quad (2)$$

Subject to:

$$\sum_{j=1}^{q} C_{ij} X_j = 1 \quad for\ all\ parts\ i = 1,..,n \quad (3)$$

Equation (3) states that only one routing will be selected for each part.

The goal behind the maximisation of the dissimilarity among alternative routings is to allow the parts to follow dissimilar routes and consequently reduce the congestion in the system.

In DMM rule, after having selected a routing for a part, this routing cannot be used by another part as long as the first part did not leave the system thus each routing can contain only one part at the time. The modification of this rule, aims to keeping the same principle but by assigning several parts to only one routing. Then if all routings are selected, the following part will be transferred in the routing where the queue of the first machine of this routing, contains at least a free place.

### 4.2 A new release of Modified Dissimilarity Maximization Method

This rule was developed based on the modified DMM rule mentioned earlier. The major motivation behind the improved modified DMM was twofold. When there are breakdowns in the system, for high arrival rate of parts and small buffer capacities, the production system is overloaded and yet the utilization rates of the machines and the material handling system are low. These two factors affect the performance of the FMS. For this, we propose the improved modified DMM rule to overcome these problems. This is because with the previous dissimilarity coefficient, the routing with the maximum total cumulative dissimilarity is selected although it can contain unavailable machines or has with busy routings the same probability of breakdowns.

Since the routing flexibility level depends on the technological capabilities and also the operational control strategies, it is necessary to implement scheduling strategies which take into account the highly uncertain nature of manufacturing systems.

Unlike to the DMM and modified DMM rules, where the dissimilarity coefficient depends on the configuration of the system and does not take into account the system state changes except for routing occupation.

In this modified DMM rule, we propose a new dissimilarity coefficient that takes into account the machines breakdowns characterised by their MTBF (means time between failures). It is defined as follows:

$$D_{ij} = \frac{\max(\overline{MTBF}_i, \overline{MTBF}_j)}{\min(\overline{MTBF}_i, \overline{MTBF}_j)} \qquad (4)$$

Where: $\overline{MTBF_i}$ and $\overline{MTBF_j}$ are the average of the MTBF of machines contained in routings *i* and *j*.

In our work, the dissimilarity coefficient which characterises the differences between the occupied routings is expressed as a function of the average of the MTBF of machines contained in the same routing. It takes its maximum value when there are significant differences between the routings in terms of MTBF values.

The goal behind the new dissimilarity coefficient is to allow the parts to avoid the routings which have the same probability of breakdowns and consequently avoid the impasses caused by the routings which fail in the same time. With this concept, it can be assured that the failures can block only a region in the system (some parts), but not all the system (all the parts).

Therefore, the new control strategy allows the system to continue producing a given set of part types despite the occurrence of unanticipated events, such as machine breakdowns.

## 5 COMPUTATIONAL RESULTS AND DISCUSSIONS

In order to analyze the impact of the modified DMM and the new release modified DMM on system performances, these methods were simulated on the FMS model described in fig. 1 based on the studied system criteria (arrival rate of part and queue size) using the same product data and layout shown in table 1. For each studied case, the rules were simulated over 20000 hours with a warm up time of 3000 hours and ten replications were made. Simulations have been carried using ARENA software, on a Core (TM) 2Duo CPU with 2.2 GHZ and 1 G of RAM.

In our analysis study, it was assumed that exponential distribution is used for occurrence of breakdown with MTBF=100hrs (Mean Time Between Failures) for the primary machines.

Although the alternate machines can process identical operations, they don't have always the same performances. In this study, it is assumed that there are two kinds of alternatives machines. The primary machine which represents the most efficient machine and the secondary machine which is more affected by breakdowns.

It is considered that the MTBF of the secondary machine is less than of the primary machine. In this section, it has been decreased by 10%. So, it can be noted that the secondary machine for an operation cannot be more efficient than the primary machine.

For maintenance time, an exponential distribution with MTTR=2 hrs (Mean Time To Repair) is used and the time between failures will only be considered when the resource is in its busy state.

This section presents some simulation results and their interpretations concerning the studied performances indicators (production rate, machines utilization rate, auto guided vehicle utilisation rate) for an overloaded system characterised by a rapid and great number of system parameters variations and for queue size equal to 2.

This capacity indicates that the buffers can only accommodate a restricted number of parts. That restriction increases the delays caused by the parts waiting times. The proposed approach is used in these constraints in order to test its performance in restrictive cases characterised usually by difficult scheduling

In order to study the effect of the experimental factors, the simulation results for the studied performances indicators are subjected to statistical analysis using the analysis of variance (ANOVA) procedure with repeated measures. Two-factors ANOVA were conducted to identify the significant differences among these indicators means:

1. Routing selection method (modified DMM and the new release modified DMM rules)
2. The system state presented by the different levels of arrival rates of parts (varied from 1/5 to 1/20)

All the tests are conducted at 5% level of significance, with the null hypothesis ($H_0$) which is that all means are equals and the alternative hypothesis ($H_1$) when there are at least two means significantly different.

| Main effects | Production rate | VTC Machines utilization rate | AGV utilization rate | critical value |
|---|---|---|---|---|
| 1 | 12,16 | 14,95 | 15,90 | 3,97 |
| 2 | 22,06 | 1,00 | 1,46 | 2,73 |
| Interaction | 1,63 | 0,68 | 0,86 | 2,73 |

Table 2: F ratio values for the performance measures

Table 2 presents the F ratio values for the different measures. In this table, it is observed that the F statistic is significant for main effect routing selection rule compared with its critical value whereas the other factor has not significant effects except for the production rate. As a result, the main effect part selection rule has a significant impact on the system performances so there are significant differences between the two rules performances. The table shows also that the interaction effect between the two factors is not significant for all the performances indicators.

The results concerning the studied performances indicators obtained using the LSD (the least significant difference) test for the main effect part launching rule are presented in a descending order in table 3.

| Routing selection method | Production rate | VTC Machines utilization rate | AGV utilization rate |
|---|---|---|---|
| New release of Modified DMM | 32,04 a | 61,99 a | 17,88 a |
| Modified DMM | 21,93 b | 44,09 b | 12,49 b |

Table 3: Multiple comparison test results for main effect routing selection method.

This table reveals that the performance of the system evaluated using various measures obtained using the new release of modified DMM are significantly better than that obtained using modified DMM. There is a substantial difference in the values of performance measures between the two methods.

Since the routing selection method effect is found to be significant for the measures such as the production rate, the machines and the AGV utilisation rates graphical plots are also obtained for these measures.

Figures 2, 3, 4 show respectively the means of 10 replications obtained for queue size equal to 2 concerning the studied performances indicators (the production rate, the VTC machines and the AGV utilisation rates) according to the arrival rates levels.

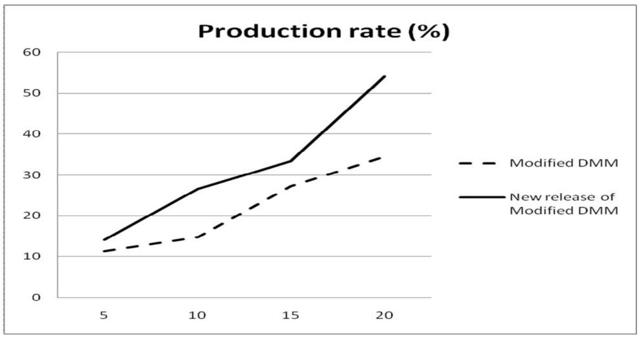


Figure 2: Production rate obtained for queue size=2.

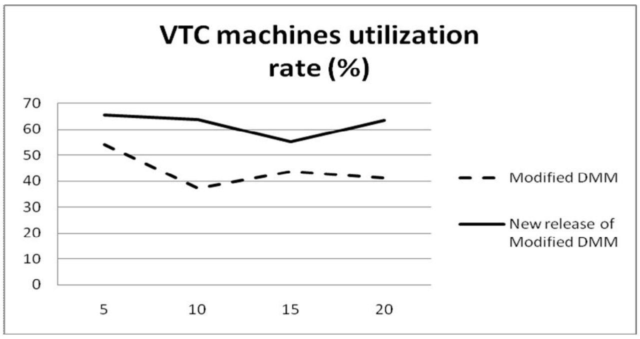


Figure 3: VTC machines utilization rate obtained for queue size=2.

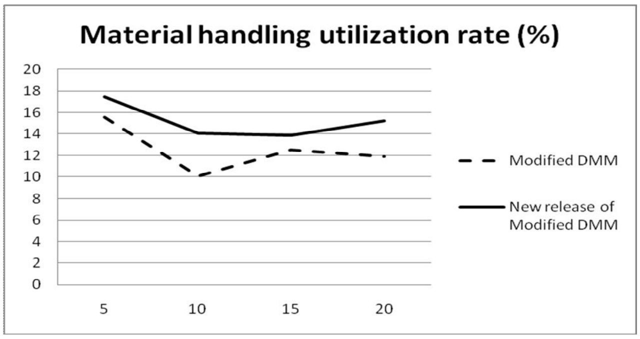


Figure 4: Material handling utilization rate obtained for queue size=2.

It is observed in Figures 2, 3 and 4 that for a significant arrival rate of parts, the production rate, the machines utilisation rate and the AGV utilization rate are clearly improved by usage of the new release of modified DMM method.

Based on the results of this study, it would appear more beneficial to focus on the use of the new release of the modified DMM rule as real time alternative routing selection approach in an attempt to improve system performance.

## 6 CONCLUSION

In this paper which represents an attempt at investigating the real time alternative routing selection problem, a new Dissimilarity Maximisation Method is proposed to select between alternatives routings, focusing on machines' failures.

This study used the modified DMM as a comparison basis to evaluate the performances of the new release of the modified DMM. Both of them have been tested on a hypothetical flexible manufacturing system in a simulation environment using ARENA software under the experimental conditions described earlier.

This FMS consists of seven machining centres, a loading and an unloading area, and six different part types. Owing to the existence of identical machining centres in the system, the part types have alternative routeings. Further, at each machine buffers, FIFO (First In First Out) is used as a priority rule for selecting parts awaiting service.

The studies indicated that the new release modified DMM rule improved the system performances by increasing the production rate, the machines and the AGV utilisation rates especially for an overloaded system with presence of resources breakdowns.

In this work, FIFO (First in first out) is used for the sequencing of each machine, but the effectiveness of the dispatching rules depends closely on the evaluated performance criterion and the effective operating conditions in the system. Thus, we suggest a real time alternative routings selection method combining the proposed approach with other dispatching rules or approaches of priority rules dynamic selection.

## REFERENCES

Akyol D.E. and O.U. Araz, 2007. A Neural Network Based Decision Support System for Real-Time Scheduling of Flexible Manufacturing Systems. *The symposium Operations Research 2007,* Saarbrücken, Germany, p 83-88.

Buyurgan, N. and C. Saygin, 2006. An integrated control framework for flexible manufacturing systems. *International Journal of Advanced Manufacturing Technology*, 27 (11-12), p. 1248- 1259.

Buyurgan, N. and C. Saygin, 2008. Application of the analytical hierarchy process for real-time scheduling and part routing in advanced manufacturing systems. *Journal of Manufacturing Systems*, 27(3), p. 101-110.

Buyurgan, N., and A. Mendoza, 2006. A Multi-objective scheduling framework for flexible manufacturing systems, *International Journal of Production Research*, 44(7), p. 1273-1295.

Caprihan, R., A. Kumar, and K.E. Stecke, 2006. A fuzzy dispatching strategy for due date scheduling of FMSs with information delays. *International Journal of Flexible Manufacturing Systems*, 18 (1), p. 29-53.

Chang, A.Y., 2007. On the measurement of routing flexibility: A multiple attribute approach. *International Journal of Production Economics,* 109 (1-2), p.122-136.

ElMekkawy, T. Y. and H.A. ElMaraghy, 2003. Real-time scheduling with deadlock avoidance in flexible manufacturing systems. *International Journal of Advanced Manufacturing Technology*, 22 (3-4), p. 259-270.

French, S. (1982), Sequencing and Scheduling: An Introduction to the Mathematics of the JobShop, Wiley, New York.

Ghosh, S. and C. Gaimon, 1992. Routing flexibility and production scheduling in a flexible manufacturing system. *European Journal of Operational Research*, 60(3), p. 344-364.

Hassam A. and Z. Sari, 2010. Selection of alternative routings in real time: DMM and modified DMM rules, *International Journal of Product Development,* Vol. 10, N°1/2/3, pp 241-258

Joseph, O. A. and R. Sridharan, 2011a. Effects of routing flexibility, sequencing flexibility and scheduling decision rules on the performance of a flexible manufacturing system. *International Journal of Advanced Manufacturing Technology,* 56(1-4), p. 291-306.

Joseph, O. A. and R. Sridharan, 2011b. Evaluation of routing flexibility of a flexible manufacturing system using simulation modelling and analysis.

*International Journal of Advanced Manufacturing Technology*, 56(1-4), p. 273-289.

MacCarthy B.L., and L. Jiyin, 1993. A new classification scheme for flexible manufacturing systems, *International Journal of Production Research*, 31(2), p299-309.

Ozmutlu, S. and C. M. Harmonosky, 2005. A real-time methodology for minimizing mean flowtime in FMSs with routing flexibility: Threshold-based alternate routing. *European Journal of Operational Research*, 166 (2), p. 369-384.

Pinedo, Michael L. (2008). Scheduling - Theory, Algorithms and Systems, Springer.

Piplani, R. and D. Wetjens, 2007. Evaluation of entropy-based dispatching in flexible manufacturing systems. *European Journal of Operational Research*, 176 (1), p. 317–331.

Rossi, A. and G. Dini, 2007. Flexible job-shop scheduling with routing flexibility and separable setup times using ant colony optimization method. *Robotics and Computer-Integrated Manufacturing*, 23 (5), p. 503-516.

Sabuncuoglu, I. and M. Lahmar, 2003. An Evaluative Study of Operation Grouping Policies in an FMS. *The International Journal of Flexible Manufacturing Systems*, 15 (3), p. 217-239.

Saygin, C. and S.E. Kilic, 1999. Integrating flexible manufacturing systems with scheduling in flexible manufacturing system, *International journal of advanced Manufacturing Technology*, 15(4), p. 268-280.

Saygin, C., F.F. Chen and J. Singh, 2001. Real-Time Manipulation of alternative Routings in Flexible Manufacturing Systems: A simulation Study. *International journal of advanced Manufacturing Technology*, 18, p 755-763.

Saygin, C. and S.E. Kilic, 2004. Dissimilarity Maximization Method for Real-time Routing of Parts in Random Flexible Manufacturing Systems, *The International Journal of Flexible Manufacturing Systems*, 16, p. 169-182.

Shahzad, M.A, 2011. *Une Approche Hybride de Simulation-Optimisation Basée sur la Fouille de Données pour les Problèmes d'ordonnancement*. Thèse de Doctorat, Université de Nantes, France.

Souier, M., A. Hassam and Z. Sari, 2010b. Des Algorithmes Basées sur les Principes des Métaheuristiques pour le Re-Ordonnancement Temps Reel dans un FMS avec Flexibilité de Routage. *Proceedings of the 8th ENIM IFAC International Conference of Modeling and Simulation* (*MOSIM'2010)*, Hammamet, Tunisie, vol 2, p.1133-1142.

Souier, M., A., Hassam and Z., Sari, 2010. Meta-heuristics for real time routing selection in FMS, *Book chapter in: Lyes Benyoucef and Bernard Grabot (Ed.), Artificial Intelligence Techniques for Networked Manufacturing Enterprises Management, Springer-Verlag*, ch. 8, pp. 221-247.

Wahab, M.I.M., and S.J. Stoyan, 2008. A dynamic approach to measure machine and routing flexibilities of manufacturing systems. *International Journal of Production Economics*, 113 (2), p. 895–913

Yu, M.C and T.J. Greene, 2009. An operational measure of routing flexibility in a multi-stage multi-product production system. *International Journal of Advanced Manufacturing Technology*, 43 (3-4), p.357-364.

Zhao, C. and Z. Wu, 2001. A Genetic Algorithm Approach to the Scheduling of FMSs with Multiple Routes. *The International Journal of Flexible Manufacturing Systems*, 13 (1), p. 71-88.